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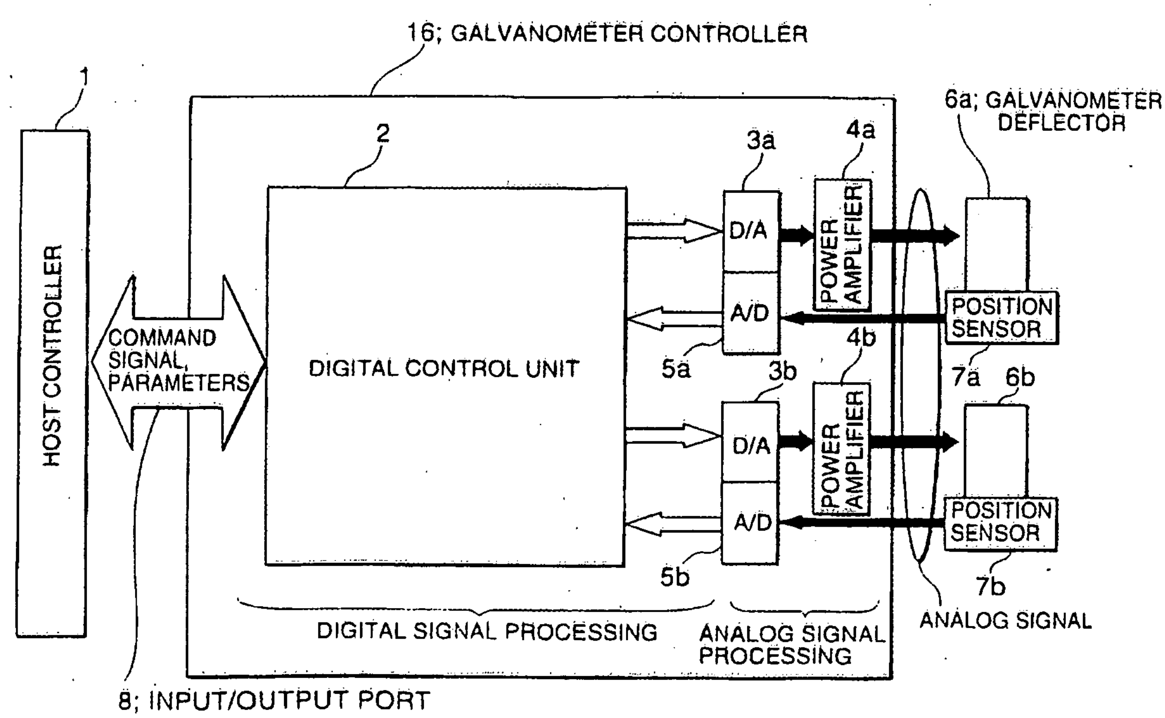
(54) Galvanometer controller and laser machining apparatus

(57) A galvanometer controller (16) capable of control with stability and with immunity to changes with time and variation in environment temperature and having improved operability and expandability, and a laser machining apparatus having the galvanometer controller (16). The galvanometer controller (16) comprises a correcting arrangement formed in a digital circuit (12), the correcting arrangement having a distortion correction section (9) for correcting a working distortion of an optical unit including a lens, an orthogonality correction section (10) for correcting the orthogonality between the two axes of the galvanometer, and a linearity correction section (11a,11b) for correcting the linearity on each of the two axes.

Fig.2



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the correcting arrangement having a distortion correction section for correcting a working distortion of an optical unit including a lens, an orthogonality correction section for correcting the orthogonality between the two axes of the galvanometer, and a linearity correction section for correcting the linearity on each of the two axes. Further, it is preferred that the galvanometer controller includes a temperature/humidity detector and characteristic controlling means for controlling a characteristic thereof according to the temperature change or humidity change.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] This above-mentioned and other objects, features and advantages of this invention will become more apparent by reference to the following detailed description of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a diagram schematically showing a machining apparatus using galvanometers to which the present invention is applied;
Fig. 2 is a diagram schematically showing the configuration of a galvanometer controller according to a first embodiment of the present invention;
Fig. 3 is a block diagram of the galvanometer control unit shown in Fig. 2;
Fig. 4 shows a set of charts for explaining distortion caused by an optical unit;
Fig. 5 shows an arithmetic circuit for correcting the distortion shown in Fig.4;
Fig. 6 schematically shows a process to determine coefficients applied to the arithmetic circuit shown in Fig. 5;
Fig. 7 shows an arithmetic circuit for correcting a orthogonal error according to the present invention;
Fig. 8 schematically shows a process to determine coefficients applied to the arithmetic circuit shown in Fig. 7;
Fig. 9 shows a set of charts for schematically explaining linearity correction according to the present invention;
Fig. 10 is another chart for schematically explaining the linearity according to the present invention;
Fig. 11 is a block diagram schematically showing a galvanometer control unit according to a second embodiment of the present invention;
Fig. 12 is a block diagram schematically showing a galvanometer control unit according to a third embodiment of the present invention.
Fig. 13 is a block diagram schematically showing a galvanometer controller according to a fourth embodiment of the present invention;
Fig. 14 shows a configuration of a position sensor in the fourth embodim nt shown in Fig.13; and
Fig. 15 schematically shows a configuration of a temperature/humidity converter table in the fourth embodiment shown in Fig.13.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] A galvanometer controller and a laser machining apparatus using the galvanometer controller will be described with reference to Figs. 1, 2 and 3. The laser machining apparatus of Fig. 1 comprises a galvanometer optical unit having an X-axis galvanometer, a Y-axis galvanometer, scanner mirrors, and a fθ lens. In Fig. 1, the laser beam is deflected for scanning by the scanner mirrors attached to the X-axis and Y-axis galvanometers and is condensed by the fθ lens on a workpiece. Fig. 2 is a diagram schematically showing the configuration of the galvanometer controller according to the first mbodiment of the present invention, and Fig. 3 shows a detail of a part in Fig. 2. In Fig.2, the laser machining apparatus has a laser beam source (not shown), galvanometer deflectors 6a and 6b which respectively reflect, along X- and Y-axes, the laser beam, position sensors 7a and 7b which respectively detect the positions of the galvanometer deflectors, a galvanometer controll r 16 which controls the galvanometer deflectors by referring to the sensed signals from the position sensors, the optical unit which condenses on the workpiece the laser beam reflected by the galvanometer deflectors, and a host controller 1 which controls the galvanometer controller.

[0018] As shown in Fig. 2, the galvanometer controller 16 is constituted by an input/output port 8 through which a digital position command signal is input from the host controller 1, a digital control unit 2 which performs digital signal processing, D/A converters 3a and 3b which convert galvanometer control outputs from the digital control unit 2 into analog signals, power amplifiers 4a and 4b which amplify outputs from the D/A converters 3a and 3b and drive the galvanometer deflectors 6a and 6b, and A/D converters 5a and 5b which are supplied with output signals from the position sensors 7a and 7b provided on the galvanometer deflectors with the X- and Y-axes, and which convert these analog signals into digital signals.

[0019] The operation of the thus-constructed galvanometer controller 16 will be described below. The position command and parameters supplied from the host controller 1 are input to the digital control unit 2. The sensed signals in analog form from the position sensors 7a and 7b on the galvanometer deflectors 6a and 6b are converted into digital signals by the A/D converters 5a and 5b. The converted digital signals are input to the digital control unit 2. On the other hand, digital signals for control of the galvanometer deflectors 6a and 6b are output from the digital control unit 2 and are converted into analog signals by the D/A converters 3a and 3b. The power amplifiers 4a and 4b amplify the converted analog signals and respectively drive the galvanometer deflectors 6a and 6b by the amplified signals. Th optical unit scans a surface of the workpiece mounted on a

$$\Delta X5 = \Delta X1 + (\Delta X2 - \Delta X1) * a / (a + b)$$

$$\Delta X6 = \Delta X3 + (\Delta X4 - \Delta X3) * a / (a + b)$$

$$\Delta Xp = \Delta X5 + (\Delta X6 - \Delta X5) * c / (c + d)$$

The correction value on the Y-axis is computed in the same way.

[0024] In the galvanometer controller 16 of this embodiment, the circuits for performing processing of various kinds including the processing for correcting a working distortion of a lens, the processing for correcting the orthogonality between the two axes, processing for correcting the linearity on each axis, and the PID control processing using the sensed position signals 13a and 13b as feedback signals, and the management table for storing and managing parameters for each correction processing are provided in the digital control unit 2, thereby making it possible to reduce changes in characteristics due to changes with time in the controller or factors in the operating environment and to thereby control the galvanometer deflectors with stability. Through control of the parameters for each processing from the host controller 1, operations for adjusting the galvanometer deflectors can be performed more easily and, further, an unskilled operator can easily perform the adjustment operations with reliability.

[0025] A galvanometer controller and a laser machining apparatus using the galvanometer controller of other embodiments of the present invention will next be described with reference to Figs. 11 and 12. Fig. 11 shows a digital control unit 2' of a second embodiment, and Fig. 12 shows another configuration of the galvanometer controller of a third embodiment. The second embodiment is characterized by performing function of reducing the influence of resonance of galvanometer deflectors. The third embodiment is characterized by performing function of automatically optimizing parameters in addition to those according to the first embodiment. In other respects, these embodiments are the same as the first embodiment. Referring to Fig. 11, the digital control unit 2' further includes notch circuits 17a and 17b. Referring to Fig. 12, the digital control unit 2" further includes an automatic tuming circuit 18. In general, a galvanometer deflector has a specific resonance frequency because of its structural characteristic. If the operating frequency of the galvanometer deflector is close to the resonance frequency, the galvanometer deflector resonates and vibration of a rotating shaft of th deflector occurs, thereby resulting in failure of accurate scanning with a laser beam. In the second embodiment, for the purpose of improving the accuracy of scanning, the notch circuits 17a and 17b are connected to the PID control blocks 12a and 12b to reduce resonating vibration of the galvanometer deflectors.

[0026] The automatic tuning circuit 18 obtains parameters from the parameter table 15 for storing and managing parameters for use in the correction processing and control processing, compares the parameters with values input in advance, performs computation using the parameters, and performs automatic control such that the parameters converge to optimum values.

[0027] As described above, the sections for the various kind corrections and the PID control blocks are incorporated in the digital unit, and additional circuits are provided in the unit 2, thereby enabling the galvanometer deflectors to be controlled with higher accuracy while achieving the same effect as that of the first embodiment.

[0028] According to the above embodiments, it is possible to prevent characteristic change in the galvanometer controller due to temperature change. However, it is still impossible to compensate characteristic change of a galvanometer itself. In general, a characteristic of a galvanometer varies due to the temperature change and humidity change and, therefore, the position sensed signal from the position sensor 7 becomes varied. A fourth embodiment shown in Fig.13 is capable of compensating the characteristic changes of a galvanometer due to the temperature change and humidity change. In Fig. 13, there are provided a temperature detector 19, a humidity detector 20 and a temperature/humidity converter table 23. The temperature detected signal and humidity detected signal from the detectors 19 and 20 are supplied to the temperature/humidity converter table 23 through A/D converters 21 and 22, respectively. In the temperature/humidity converter table 23, a gain factor for the sensed position signal Vp produced in the position sensor 7 is predeterminedly stored. In this case, the position sensed error due to the temperature change and humidity change are previously measured in practice and after this, the gain factor for compensating the position sensed error is determined and stored in the table. Alternatively, if the gain factor can be expressed by a functional equation according to the temperature change and humidity change, it may be possible to make up the table 23 by apply at least one function table. Further, when extent of the position sensed error is varied according to the position of the galvanometer, the gain factor is determined according to the sensed position in addition to the temperature and humidity. The gain factor data Dg are outputted from the table 23 and applied the position sensor 7 through a D/A converter 24.

[0029] In Fig.14 showing the position sensor 7, an initial position sensed signal level from an angle detector 25 is controlled in response to the gain factor signal Vg from the D/A converter 24. In Fig.15 showing one example on the temperature/humidity converter table 23, the temperature data Dt and the humidity data Dw are converted in function tables 27 and 28 and the converted data are multiplied. Further, the multiplied data are corrected by an individual differenc factor Ky depend-

Fig.1

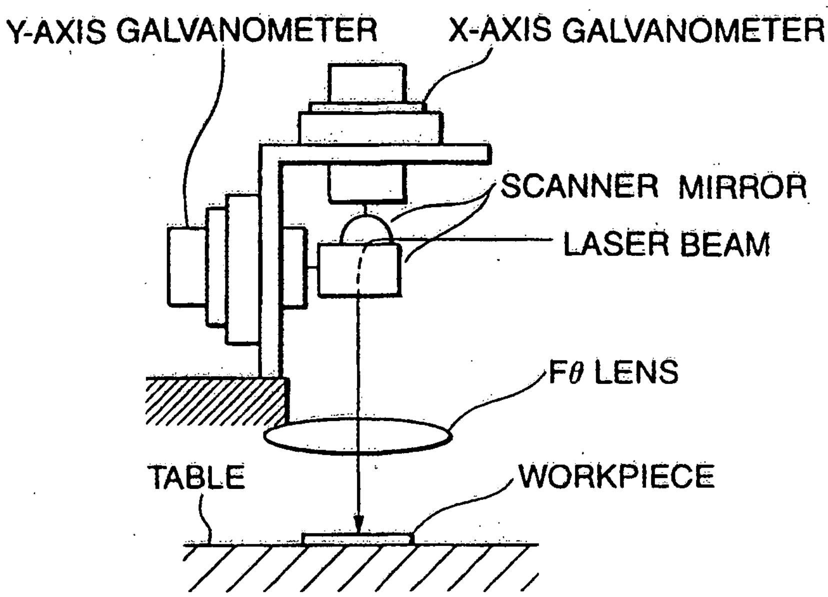

Y-AXIS GALVANOMETER
X-AXIS GALVANOMETER
SCANNER MIRROR
LASER BEAM
Fθ LENS
TABLE
WORKPIECE

Fig.3

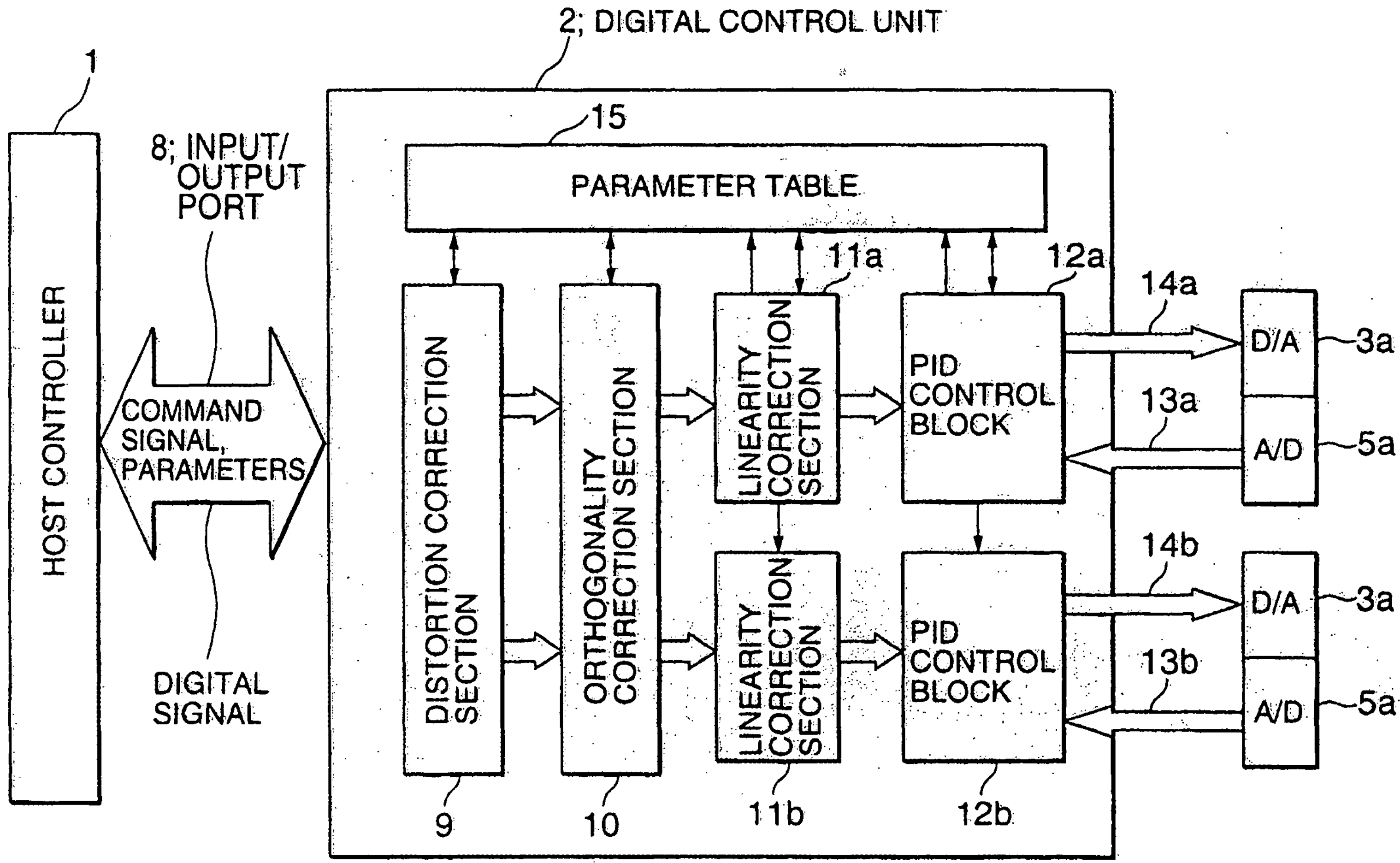

2; DIGITAL CONTROL UNIT
1
HOST CONTROLLER
8; INPUT/ OUTPUT PORT
COMMAND SIGNAL, PARAMETERS
DIGITAL SIGNAL
15
PARAMETER TABLE
DISTORTION CORRECTION SECTION
9
ORTHOGONALITY CORRECTION SECTION
10
LINEARITY CORRECTION SECTION
11a
LINEARITY CORRECTION SECTION
11b
PID CONTROL BLOCK
12a
PID CONTROL BLOCK
12b
14a
13a
14b
13b
D/A
3a
A/D
5a
D/A
3a
A/D
5a

Fig.6

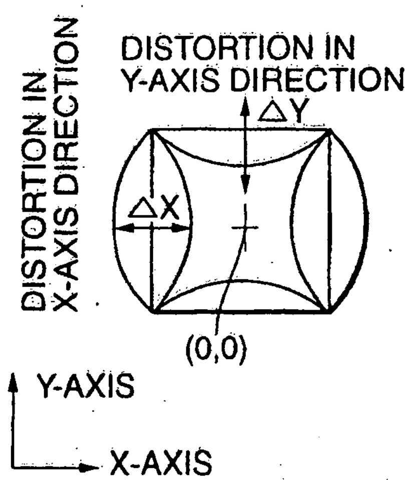

DISTORTION IN
X-AXIS DIRECTION
DISTORTION IN
Y-AXIS DIRECTION
△Y
△X
(0,0)
Y-AXIS
X-AXIS

Fig.7

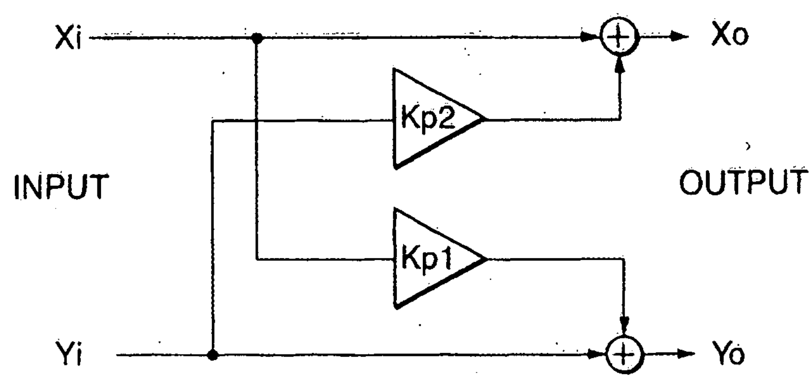

Xi
INPUT
Yi
Kp2
Kp1
Xo
OUTPUT
Yo

Fig.9

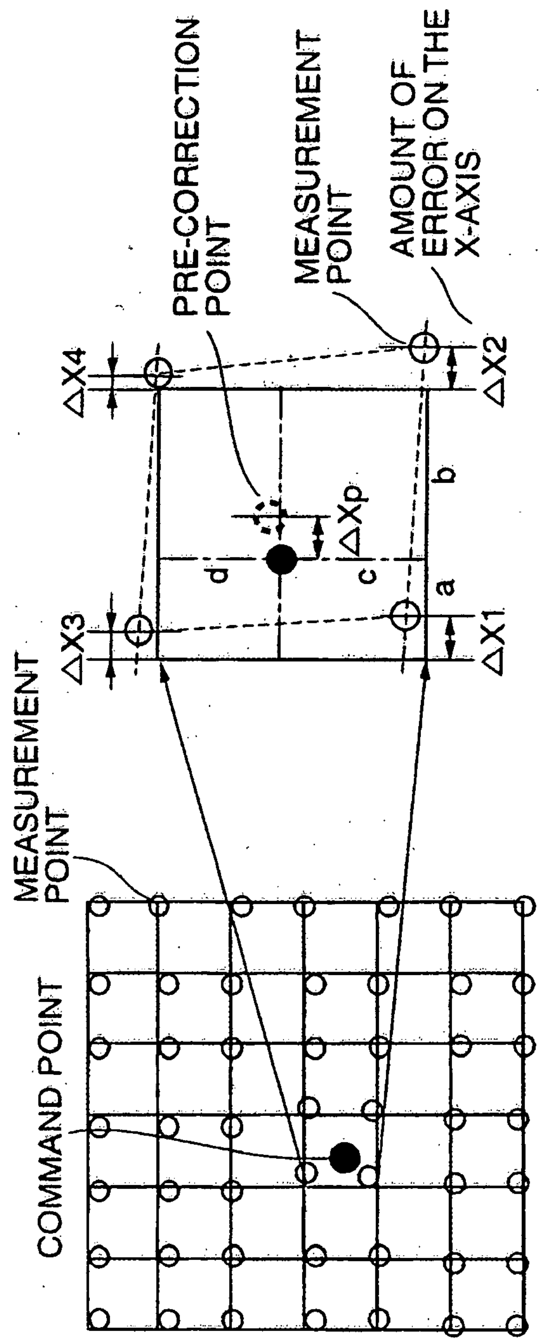

PRE-CORRECTION POINT
MEASUREMENT POINT
AMOUNT OF ERROR ON THE X-AXIS
△X4
△X3
△X2
△X1
△Xp
a
b
c
d
MEASUREMENT POINT
COMMAND POINT

Fig.11

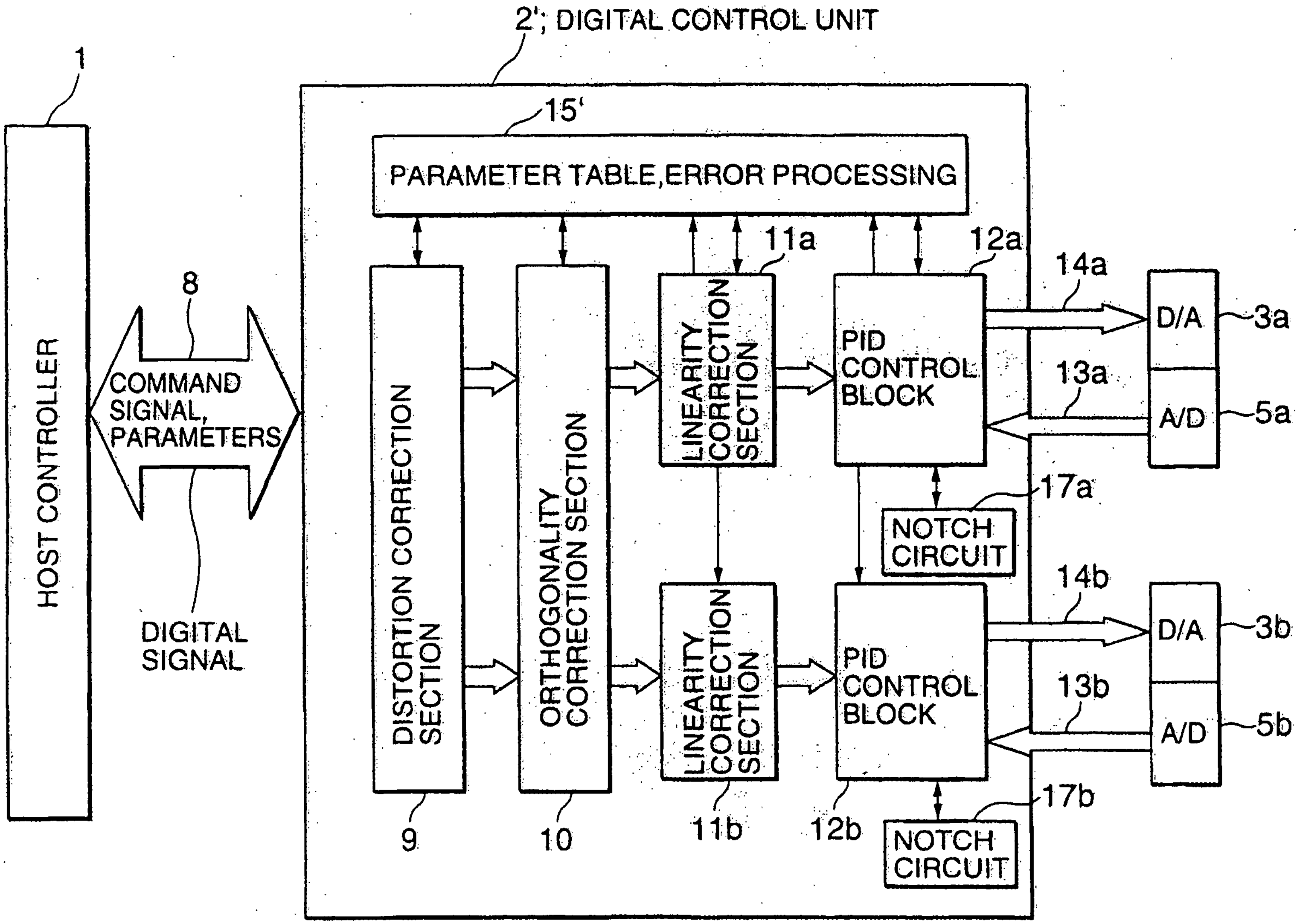
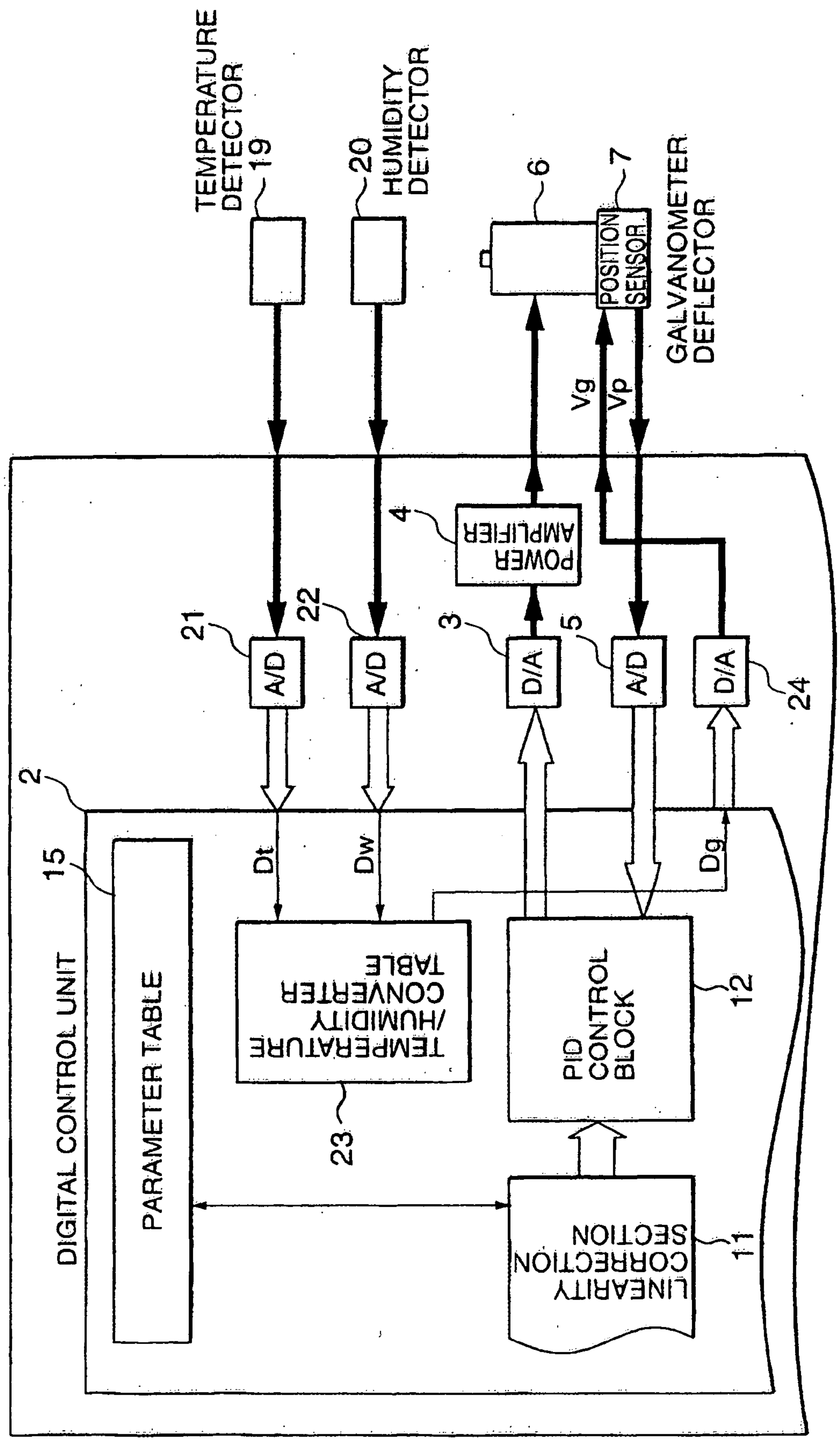

2'; DIGITAL CONTROL UNIT
1
HOST CONTROLLER
8
COMMAND SIGNAL, PARAMETERS
DIGITAL SIGNAL
15'
PARAMETER TABLE,ERROR PROCESSING
DISTORTION CORRECTION SECTION
9
ORTHOGONALITY CORRECTION SECTION
10
11a
LINEARITY CORRECTION SECTION
LINEARITY CORRECTION SECTION
11b
12a
PID CONTROL BLOCK
PID CONTROL BLOCK
12b
17a
NOTCH CIRCUIT
17b
NOTCH CIRCUIT
14a
13a
D/A
3a
A/D
5a
14b
13b
D/A
3b
A/D
5b

Fig.13


TEMPERATURE DETECTOR
19
20
HUMIDITY DETECTOR
6
7
POSITION SENSOR
GALVANOMETER DEFLECTOR
Vg
Vp
4
POWER AMPLIFIER
21
A/D
22
A/D
3
D/A
5
A/D
D/A
24
2
Dt
Dw
Dg
15
PARAMETER TABLE
DIGITAL CONTROL UNIT
TEMPERATURE /HUMIDITY CONVERTER TABLE
23
PID CONTROL BLOCK
12
LINEARITY CORRECTION SECTION
11